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Impact of information transfer on farmers' uptake of innovative crop technologies: a structural equation model applied to survey data

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Abstract This study analyses the impact of the transfer of technological information (among other a priori identified factors) on the uptake of innovative crop technologies using structural equation modelling of data from a representative survey of Scottish crop farmers. The model explains 83% of the variance in current technological uptake behaviour and 63% of the variance in intentions to uptake new technologies. Results show economic characteristics (profit orientation, agricultural income, technological investment behaviour and farm labour) to have the strongest effect on both uptake and intentions to uptake novel technologies. Education, access to technological information and perceived usefulness of sources of information transfer are also main influences on behaviour and intentions. Technological uptake behaviour is a strong determinant of intentions to uptake more technologies in the future. The results confirm established evidence from the

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literature that, besides economic factors, access to technological information and trust in/perceived usefulness of the different information sources will have an impact on technological uptake. The findings are highly policy relevant as they give some indication of the factors influencing the process of targeting specific technological information transfer through the appropriate channels to agricultural producers, which builds a potential driver of behavioural change.

Keywords Technological uptake · Technological information transfer · Structural equation model · Scottish crop farmers

JEL Classification Q160 · D830 · C830

1 Introduction

The changing demands on agricultural production due to food security, sustainable intensification, climate change and changes in consumer diets call for continuous technological innovation. Increasingly during the recent decades technology has developed to meet the needs of a sustainable agriculture focused on increasing production at least cost to the environment. From a focus on higher-yielding crops combined with high use of fertilisers and pesticides, crop technologies have evolved to include precision farming, biological control, nitrogen fixing. Current Scottish agricultural policy underlines the importance of widespread adoption by farmers of innovative technologies and practices to further improve the industry's performance, in which a significant role is played by the active exchange of technological knowledge between research and farming communities (through e.g., use of demonstration farms, training, education and advice to facilitate the sharing of innovative and best practices, Scottish Government 2015).

The literature on the adoption of technological innovations in agriculture has focused in its early stages on the diffusion process, with the well-known S-shaped diffusion curve (Tarde 1903), which depicts a slow start when only a few farmers adopt the innovation, followed by adoption expanding at an increasing time rate, then decreasing as the number of adopters begins to exceed the number of farmers who have not yet adopted until asymptotically approaching its maximum level when the process ends. This was further discussed by rural sociologists and introduced to economics by Griliches in 1957 (as cited by Fernandez-Cornejo et al. 1994).

The study of technological adoption has evolved to include the analysis of adoption determinants in order to understand what causes the differences in adoption rates and what the constraints to the adoption of innovations are. While early adoption studies focused primarily on technological innovations that increased farm productivity, more recently the focus has shifted towards studies on the adoption of environmentally friendly technologies. There is an ever growing literature analysing technology adoption behaviour in agriculture, part of which focussing on the factors that influence it (Rahm and Huffman 1984; Caswell and Zilberman 1985; Feder and Umali 1993; Fairweather and Keating 1994; Beedell and Rehman 2000; Nuthall 2001; Sharma et al. 2011). Farmers' uptake of innovative crop technologies has occurred at a different pace depending on technology cost, regulatory framework, socio-economic characteristics, influence of peers, attitudes towards innovation, perceptions of risk, etc. Among these factors, access to technological information and knowledge transfer are among the key influences on adoption behaviour.

This study builds on the existing literature and analyses the impact of the transfer of technological information (among other a priori identified factors) on the adoption of innovative crop technologies by Scottish farmers. We used a dataset collected through a stratified telephone survey and structural equation modelling (SEM) to test a conceptual model based on behavioural economics theory.

2 Method and data

2.1 Conceptual model

Based on a review of the literature and expert opinion, we built and tested three research hypotheses:

Hypothesis 1 Education, technology knowledge and information transfer influence uptake and intentions to uptake novel crop technologies.

Earlier adoption literature viewed the lack of access to information and knowledge transfer as the main reason preventing farmers from adopting new techniques. Hägerstrand (1952) introduced a model in which interpersonal communications were considered particularly important in the temporal and spatial differences in the adoption of innovations. Rogers and Shoemaker (1971) found that early adopters tended to be more educated and have better access to information. Lin (1991) found a positive effect of education on the adoption and intensity of farm innovation (a hybrid rice variety). He pointed out that more educated farmers are better prepared to manage the risk related to imperfect information about new technologies. More educated farmers may be better able to process new information more effectively (Fernandez-Cornejo et al. 2005). Läßle et al. (2015) state that the positive effect of agricultural education on farm innovation may be due to farmers' awareness of available innovations being increased through agricultural education, or to education being connected to human capital. Rahm and Huffman (1984) found that human capital variables—including education—may enhance the efficiency of adoption decisions. However a number of studies found education not to be significantly related to adoption behaviour, for instance the study by Shapiro et al. (1992) on double-cropping of soybeans and wheat. Others such as Harper et al. (1990) found that higher education increased the probability of adoption of one pest management strategy, while reducing the adoption of another. Gould et al. (1989) found education to be negatively related to the adoption of soil conservation technologies. There are different reasons for the divergence in the findings regarding the impact of education on adoption, the most obvious one being related to the specifics of each technology. For instance, the information requirements of precision agriculture technologies are heavier than others' and some studies (Walton et al. 2008; Larson et al. 2008) found that the associated human capital requirements are more likely to be met by farmers with a higher level of education. However, even for simpler technologies such as soil testing or conservation tillage, college education has been found to have a positive influence on adoption (Fuglie 1999; Wu and Babcock 1998; Soule et al. 2000).

Griliches (1957) and other early adoption studies in the field of agricultural economics did not consider learning and the communications process. This issue was gradually introduced in subsequent decades. Ruttan (1996) stated that a positive aspect of the convergence of the application of economic and sociological methodologies has been the

identification of the learning behaviour as a key factor in the adoption process. Tsur et al. (1990) introduce learning as a dynamic factor into modelling innovation adoption and determine how perceptions about the performance of the innovation are updated. They consider two types of learning, namely collecting and processing information and learning by doing (i.e., gaining information by using the new technology).

In addition to analysing the role of learning in the adoption process, access to various information transfer sources and their perceived value by farmers has been found to influence adoption. Birkhaeuser et al. (1991) found that agricultural extension services are a key source of technological information transfer. Sanyang et al. (2009) in their study examining technology transfer to farmers in the areas of production and marketing of vegetables found public extension system and farmer groups as sources of technology dissemination to farmers. Availability of information, its costs of acquisition and sources such as the social network in which the farmer operates, extension officers, scientists and agricultural researchers, are critical factors in influencing farmers' perceptions towards new technologies and potentially adoption behaviour (Wheeler 2009). Farmers with access to sources of technical knowledge and information such as extension officers and industry related media are likely to have more accurate expectations of the distribution of the profitability of the innovation (Ghadim and Pannell 1999).

Hypothesis 2 Economic characteristics (income and labour) influence uptake of and intentions to uptake novel crop technologies.

Many studies show that farmers are more likely to uptake new technologies if there is a guarantee of a higher income after adoption (Areal et al. 2011; Adrian et al. 2005). Some new technologies reduce farmers' costs as they might involve lower expenditures on inputs (pesticides, labour, machinery or fuel) (Bernard et al. 2004; Qaim 2009), more flexible crop management in terms of time freed from pesticide spraying (Keelan et al. 2009) or, in the case of precision farming, provide considerable amount of information to help with farm management (Olson 1998). Thus larger farms with higher agricultural inputs costs may be seen as more likely to uptake these technologies.

However having a higher income is often a prerequisite for adoption. Some technologies are more costly to implement and, while many of the new ones are appealing for more than just financial reasons—e.g., environmental benefits related to low herbicide use, nitrogen fixing and conservation tillage practices (Dewar et al. 2003; Smyth et al. 2011; Powlson et al. 2011)—and as such not only to profit-oriented farms, technological uptake might be more difficult to implement by the smaller businesses. Adrian et al. (2005) found that larger farms are more likely to be able to invest the large amount of capital required by precision farming technologies than smaller farms. Rogers and Shoemaker (1971) found that early adopters tended to be wealthier, specialised and had larger size farms. Farm size may relate to income (Rogers and Stanfield 1968). It has been suggested that larger farms can take advantage of returns to scale (Rahm and Huffman 1984) and are less likely to face credit constraints because they have more collateral. Fixed costs related to information acquisition, loan fees, time to obtain materials and lower risk aversion in larger farms are also thought to lead these farmers to adopt first (Feder and O'Mara 1981).

Availability of labour can also be a prerequisite for adoption of labour-intensive technologies such as integrated pest management (IPM) (Fernandez-Cornejo et al. 1994). Ghadim and Pannell (1999) found that a farm with larger number of workers per hectare is more likely to be in a position to trial and continue using a potentially profitable innovation. In contrast, a labour shortage can have a positive effect on innovation activities as it may induce the adoption of labour saving technologies (Hayami and Ruttan 1985).

Hypothesis 3 Technological uptake behaviour influences intentions to uptake crop technologies.

Adoption studies acknowledge the possibility of a dependence path, i.e., farmers' technology adoption behaviour may be partly dependent on their earlier technology choices (Wu and Babcock 1998; Khanna 2001; Teklewold et al. 2013). Wu and Babcock (1998) state that ignoring these inter-relationships may lead to underestimating or overestimating the influence of various factors on the adoption decision and on the impacts of adoption. Thus analysing adoption behaviour in a multiple technology choice modelling framework is important to capture the information contained in interdependent adoption decisions (Dorfman 1996).

Farmers are more likely to adopt a mix of technologies to tackle a multitude of agricultural production constraints than to adopt a single technology. Experience with similar innovations improves the technical and management skills of the farmers and will most likely influence adoption positively (Ghadim and Pannell 1999).

They are faced with technology alternatives that may be adopted simultaneously and/or sequentially as complements, substitutes, or supplements, which suggests path dependence (Cowen and Gunby 1996; Kassie et al. 2013).

Identifying which factors influence adoption of a mix of technologies becomes a complex issue. Khanna (2001) recognises that the same unobserved factors could influence joint adoption decisions. Rauniyar and Goode (1992) examined the adoption of seven different technologies by maize farmers, ranging from high-yield seed varieties to chemical uses to planting methods. Using factor analysis, they found that the seven technologies could be grouped into three interrelated sets of technologies which appeared to have common factors influencing their adoption.

A small majority of the adopters in our study stated to have applied more than one technology. Thus, rather than focusing on specific determinants of adoption of each technology, this analysis builds latent variables of technological uptake and intentions (similar to Rauniyar and Goode 1992) and tests the impact of factors common to all technologies with the aim to demonstrate what proportion of the variance in technological uptake/intentions is explained by these factors.

The conceptual model based on the aforementioned hypotheses is depicted in Fig. 1.

2.2 Method

We used a structural equation model (SEM) with observed and latent variables to test the conceptual model and assess the strength of the research hypotheses, namely the effects the behavioural determinants have on the technology adoption intentions and behaviour and on each other. As each variable might influence behaviour and intentions both directly or indirectly (through their effect on other variables in the model, which subsequently directly influence behaviour), the variance explained by the model is higher than when other methods, e.g., regression analysis, are used.

The model consists of two parts: the measurement model (which stipulates the relationships between the latent variables and their component indicators), and the structural model (which describes the causal relationships between the latent variables). The model is defined by the following system of three equations in matrix terms (Jöreskog and Sörbom 2007):

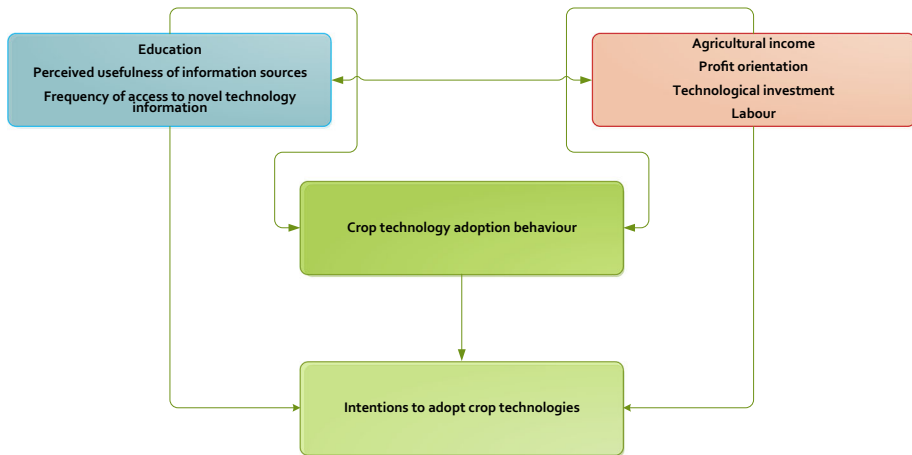


Fig. 1 Conceptual model

The structural equation model: $\eta = B\eta + \Gamma\zeta + \zeta$

The measurement model for y : $y = A_y\eta + \varepsilon$

The measurement model for x : $x = A_x\eta + \varepsilon$

where: η is an $m \times 1$ random vector of endogenous latent variables; ζ is an $n \times 1$ random vector of exogenous latent variables; B is an $m \times m$ matrix of coefficients of the η variables in the structural model; Γ is an $m \times n$ matrix of coefficients of the ζ variables in the structural model; ζ is an $m \times 1$ vector of equation errors (random disturbances) in the structural model; y is a $p \times 1$ vector of endogenous variables; x is a $q \times 1$ vector of predictors or exogenous variables; A_y is a $p \times m$ matrix of coefficients of the regression of y on η ; A_x is a $q \times n$ matrix of coefficients of the regression of x on ζ ; ε is a $p \times 1$ vector of measurement errors in y ; δ is a $q \times 1$ vector of measurement errors in x .

We estimate the model using the Diagonally Weighted Least Squares (DWLS) method and the statistical package Lisrel 8.80 (Jöreskog and Sörbom 2007). We combine Prelis to calculate the asymptotic covariance matrix (Muthén 1984; Bollen 1989) and Lisrel to compute test statistics for the estimation of the significance of causal relationships (Jöreskog and Sörbom 2007). DWLS estimation method is consistent with the types of variables included in the model (ordinal and categorical) and the deviation from normality in these variables (Finney and DiStefano 2006). The model is validated using absolute (root mean square error of approximation and goodness of fit index), incremental (adjusted goodness of fit index, non-normed fit index, normed fit index, relative fit index, comparative fit index and incremental fit index) and parsimonious (normed Chi square) goodness of fit (GoF) indicators (Hair et al. 2006). An acceptable level of overall goodness-of-fit does not guarantee that all constructs meet the requirements for the measurement and structural models. The validity of the SEM is assessed in a two-step procedure, the measurement model and the structural model. Model selection is performed through a nested model approach, in which the number of constructs and indicators remains constant, but the number of estimated relationships is changed iteratively.

2.3 Data

The data used in this study are drawn from a representative telephone survey of Scottish agricultural holdings, which was completed in September 2013. The main aim of the survey was to identify the impact of the previous and current CAP reforms on structural changes and the technological uptake on Scottish farms. The sampling frame (10,000 farms) was derived from the June Agricultural Census (JAS) and stratified by region, activity, size and farming enterprise. A potential limitation of the study is related to the JAS under-representation of 'very very small' farms (business holdings with less than 0.5 standard labour requirements). However, based on findings from the literature confirmed by this study that larger farms are more likely to uptake technologies (Adrian et al. 2005), we consider this potential bias to be inconsequential to the results of the analysis. This study analyses data for 450 crop farms from a total of 2416 fully completed questionnaires from livestock, crop and mixed farms.

The part of the questionnaire used in this analysis and consistent with the aim of testing the research hypotheses and the use of SEM included close-ended questions on the following: socio-economic characteristics (education, agricultural income, profit orientation, number of employees); perceived usefulness of information sources (open days, monitor/demonstration activities, meetings with other farmers, internet, agricultural consultants, government information sources, representatives of research/educational organisations); frequency of access to novel technological information (precision farming technologies; new tillage practices; new or novel crops; GM crops; alternatives to pesticides such as use of biological control methods, elicitors; varieties of nitrogen fixing plants and/or legumes); changes in the amount invested in new technologies (actual change, intention to and perceived difficulty to change); crop technology adoption behaviour during the past ten years (precision farming technologies; new tillage practices; new or novel crops; GM crops; biological control methods, elicitors; varieties of nitrogen fixing plants and/or legumes); and intentions to adopt crop technologies during the next ten years (precision farming technologies; new tillage practices; new or novel crops; GM crops; biological control methods, elicitors; varieties of nitrogen fixing plants and/or legumes).

Table 1 presents a description of the latent variables and their corresponding indicators included in the SEM model.

Almost half (45%) of the farmers in our sample have applied one or more crop technologies and about a third (34%) intend to uptake. From the farmers who either currently uptake or intend to uptake technologies, two-thirds (64%) and, respectively more than half (57%) exhibit multiple technology adoption behaviour/intentions (Fig. 2).

As regards choice of technologies, more than a quarter (29%) of farmers currently use or are in process of implementing precision farming technologies, followed by about a fifth (21%) of farmers using or in process of implementing varieties of nitrogen fixing plants/legumes, and about a fifth (19%) of farmers using or in process of implementing new tillage practices. About a tenth (11 and 10%) of farmers adopted biological control methods/elicitors and respectively novel crops, and only 2% GM crops during the past ten years. As regards farmers' intentions, the same ranking applies with similar percentages for the three most popular technologies and slightly higher numbers for the other three.

As regards sample description, 83% of the respondents are male and 17% female, 46% of farmers are under 55 years old, 68% completed college or university studies, 88% manage profit-oriented enterprises and 72% own their farm. About a quarter (24%) of

Table 1 Description of latent variables and their corresponding indicators

Latent variables	Indicators (statements)	Values and labels
Educs	Educ (educational level)	1 (school), 2 (college), 3 (university or higher)
Profits	Profit (Is this enterprise operated for profit?)	1 (yes), 2 (no, but it is important that it breaks even), 3 (no, we expect to make a loss)
Employs	Employ (How many people are employed on this land?)	1 (none), 2 (1–3), 3 (4–10), 4 (more than 10)
Income	Income1 (How much of your total income from this business/holding is from agriculture on this farm)	1 (zero), 2 (less than 25%), 3 (around 25% to 50%), 4 (around 50% to 75%), 5 (over 75%)
	Income2 (How much of your total income from this business/holding is from the Single Farm Payment (SFP))	
Chtech	Income3 (Do you receive a Single Farm Payment)	1 (no), 2 (yes)
	Chtech1 (Since 2005 have any of the following changed the way you manage your business/holding: changes in technological investment)	1 (no), 2 (slightly), 3 (significantly)
	Chtech2 (Since 2005 have you changed: the amount invested in new technologies)	1 (decrease), 2 (no change), 3 (increase)
	Chtech3 (By 2020 do you intend to change: the amount invested in new technologies)	1 (decrease), 2 (no change), 3 (increase)
	Chtech4 (How easy would you find it to make the following changes to your business/holding: the amount invested in new technologies)	1 (1), 2 (2), 3 (3), 4 (4), 5 (5)
Info	In terms of getting ideas on strategic decisions (medium & long term development of the business/holding), how useful do you find:	1 (not at all useful), 2 (slightly useful), 3 (useful), 4 (very useful), 5 (extremely useful)
	Info1 (attending open days, monitor/demonstration activities)	
	Info2 (meeting with other farmers)	
	Info4 (consulting the internet)	
	Info5 (asking for advice from agricultural consultants)	
	Info6 (consulting Government information sources)	
	Info7 (consulting representatives of research/educational organisations)	

Table 1 continued

Latent variables	Indicators (statements)	Values and labels
Techinfo	In order to keep on track with developments on various issues related to your business/holding, how often do you look for information on:	1 (never), 2 (yearly), 3 (monthly), 4 (weekly)
	Tecinfo1 (adoption of precision farming technologies)	
	Tecinfo2 (adoption of new tillage practices)	
	Tecinfo3 (adoption of new or novel crops)	
	Tecinfo4 (adoption of GM crops)	
	Tecinfo5 (adoption of alternatives to pesticides such as use of biological control methods, elicitors, etc.)	
Uptech	Tecinfo6 (adoption of varieties of nitrogen fixing plants and/or legumes)	
	Since 2005 have you applied/started to apply on your business/holding any (technological) innovations: Uptech1 (precision farming technologies)	1 (no), 2 (in process), 3 (yes)
	Uptech2 (new tillage practices)	
	Uptech3 (new or novel crops)	
	Uptech4 (GM crops)	
	Uptech5 (biological control methods, elicitors)	
Intech	Uptech6 (varieties of nitrogen fixing plants and/or legumes)	
	In the next ten years are you planning to apply on your business/holding any (technological) innovations: Intech1 (precision farming technologies)	1 (no), 2 (yes)
	Intech2 (new tillage practices)	
	Intech3 (new or novel crops)	
	Intech4 (GM crops)	
	Intech5 (biological control methods, elicitors)	
	Intech6 (varieties of nitrogen fixing plants and/or legumes)	

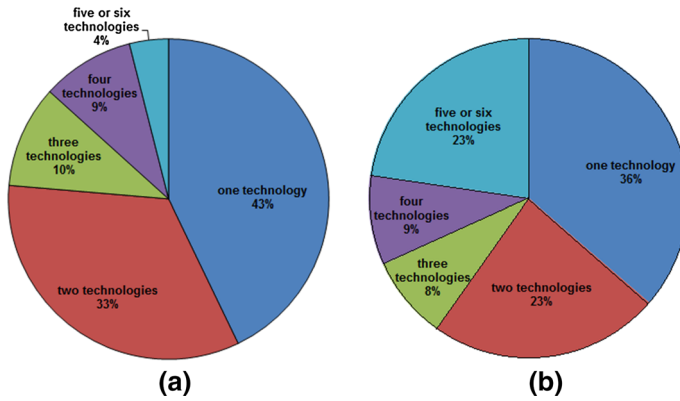


Fig. 2 Farmers' uptake of technologies (a) and intentions to uptake technologies (b)

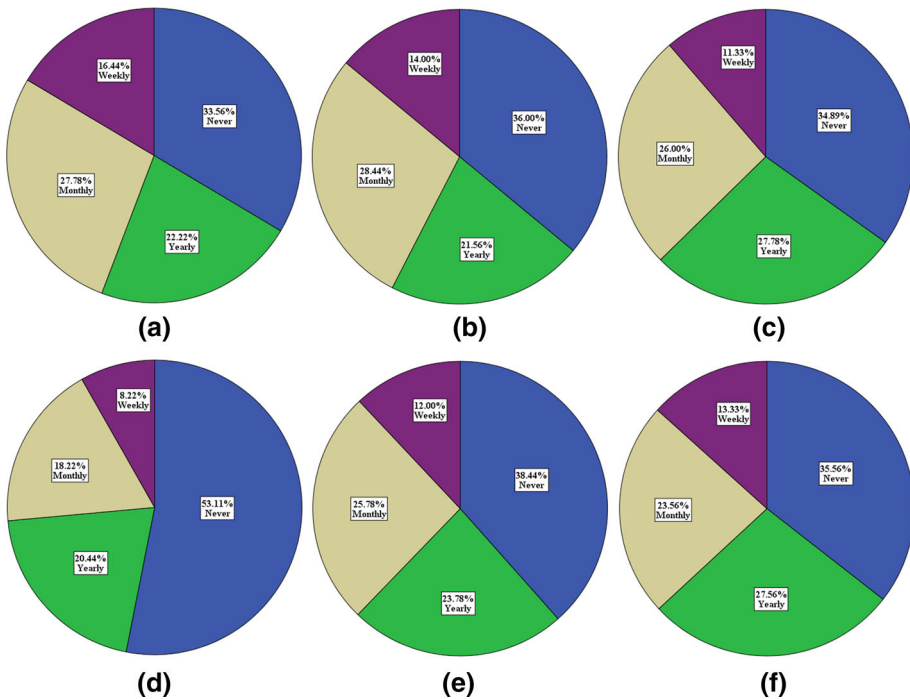


Fig. 3 Farmers' frequency of access to information on **a** adoption of precision farming technologies; **b** adoption of new tillage practices; **c** adoption of new or novel crops; **d** adoption of GM crops; **e** adoption of alternatives to pesticides such as use of biological control methods, elicitors; **f** adoption of varieties of nitrogen fixing plants and/or legumes

farmers search weekly for information about one or more technologies. Figure 3 presents the frequency of access to information about different technologies.

Table 2 presents some descriptive statistics for the variables included in the model.

Table 2 Descriptive statistics

Latent variables	Indicators	Cronbach alpha	Mean Statistic	SD Statistic	Skewness		Kurtosis	
					Statistic	SE	Statistic	SE
Educs	Educ	–	1.94	.758	.104	.115	–1.253	.230
Profits	Profit	–	1.16	.457	2.972	.115	8.082	.230
Employs	Employ	–	1.66	.738	.897	.115	.298	.230
Income	Income1	.531	3.90	1.315	–.893	.115	–.470	.230
	Income2		2.29	.942	.493	.115	.084	.230
	Income3		1.80	.400	–1.505	.115	.266	.230
Chtech	Chtech1	.567	1.84	.791	.284	.115	–1.350	.230
	Chtech2		2.43	.509	.137	.118	–1.595	.235
	Chtech3		2.38	.512	.197	.122	–1.306	.244
	Chtech4		2.95	1.125	–.065	.117	–.675	.233
Info	Info1	.794	2.90	1.194	–.239	.115	–.862	.230
	Info2		3.18	1.126	–.476	.115	–.385	.230
	Info4		2.76	1.212	–.018	.115	–.872	.230
	Info5		2.98	1.184	–.321	.115	–.749	.230
	Info6		2.48	1.149	.109	.115	–.987	.230
	Info7		2.62	1.203	.014	.115	–1.099	.230
Techinfo	Tecinfo1	.903	2.27	1.096	.202	.115	–1.311	.230
	Tecinfo2		2.20	1.079	.258	.115	–1.279	.230
	Tecinfo3		2.14	1.023	.362	.115	–1.077	.230
	Tecinfo4		1.82	1.005	.865	.115	–.567	.230
	Tecinfo5		2.11	1.054	.390	.115	–1.155	.230
	Tecinfo6		2.15	1.051	.397	.115	–1.098	.230
Uptech	Uptech1	.634	1.54	.874	1.030	.116	–.894	.232
	Uptech2		1.37	.771	1.624	.117	.672	.234
	Uptech3		1.20	.600	2.655	.116	5.106	.231
	Uptech4		1.04	.271	7.006	.116	47.711	.232
	Uptech5		1.20	.597	2.650	.116	5.117	.231
	Uptech6		1.40	.787	1.515	.116	.344	.231
Intech	Intech1	.859	1.25	.435	1.141	.118	–.702	.236
	Intech2		1.14	.350	2.056	.119	2.240	.237
	Intech3		1.16	.367	1.860	.118	1.468	.235
	Intech4		1.07	.251	3.467	.118	10.064	.235
	Intech5		1.14	.349	2.068	.117	2.287	.234
	Intech6		1.20	.401	1.502	.118	.256	.235

3 Results

The model explains 83% of the variance in current adoption behaviour and 63% of the variance in intentions to adopt new technologies. All variables have a statistically significant effect on uptake of and intentions to uptake innovative technologies.

Table 3 Goodness of fit indicators

GoF indicators	Estimated value	Recommended value
Degrees of freedom (df)	523	–
Satorra-bentler scaled Chi square	652.02	–
Normed Chi square (Chi square/df)	1.25	[1–3]
Root mean square error of approximation (RMSEA)	0.084	0.00–0.10
Goodness of fit index (GFI)	0.97	0.90–1.00
Normed fit index (NFI)	0.98	0.90–1.00
Non-normed fit index (NNFI)	0.99	0.90–1.00
Comparative fit index (CFI)	1.00	0.90–1.00
Adjusted goodness of fit index (AGFI)	0.97	0.90–1.00
Relative fit index (RFI)	0.97	0.90–1.00
Incremental fit index (IFI)	1.00	0.90–1.00

The model has very good fit according to the measures of absolute, incremental and parsimonious fit (Hair et al. 2006). The main goodness of fit (GoF) indicators (estimated and recommended values) for the estimated model are presented in Table 3.

Additional testing of the appropriateness of the model was achieved by comparing the estimated model with two other models that acted as alternative explanations to the proposed model in a competing models strategy using a nested model approach. The results across all types of goodness-of-fit measures favoured the estimated model in most cases. Therefore, we confirmed the accuracy of the proposed model and discarded the competing ones.

After assessing the overall model and aspects of the measurement model, the standardised structural coefficients were examined for both empirical and theoretical implications. Table 4 presents the standardised total effects between the latent variables in the model.

The path diagram for the estimated SEM model is presented in Fig. 4.

Economic factors have the strongest influence on technological uptake and intentions. A profit-oriented farmer with a higher proportion of their income deriving from agriculture, who employs more farm labour, with positive investment behaviour, whose investment in technology had stronger effect on their business and who finds it easier to invest in technology is more likely to exhibit technological uptake behaviour and/or intent to uptake technologies.

Profit orientation has a strong direct effect on behaviour and an indirect effect—through behaviour—on intentions and explains 81% and, respectively, 49% of their variance *ceteris paribus*. This confirms findings from the established literature that technological adoption behaviour is intrinsically linked to the economic and financial behaviour of the farm (Rogers and Shoemaker 1971; Adrian et al. 2005; Mariano et al. 2012).

Agricultural income strongly influences adoption intentions directly and indirectly – through behaviour—with a total effect of 67% *ceteris paribus*. It has an indirect effect (54% *ceteris paribus*) on adoption through profit orientation and the information variables. This is consistent with findings from the literature that income—or farm size, which usually is considered a proxy for income (Rogers and Stanfield 1968)—positively influences adoption (at least in its early stage) (Rogers and Shoemaker 1971; Adrian et al. 2005). Agricultural income's influence on profit orientation (59% *ceteris paribus*) is logical as higher income

Table 4 Standardised total (direct and indirect) effects (*t* values in parentheses)*

Observed/ latent variables	Total effects on 'profits'	Total effects on 'chtech'	Total effects on 'info'	Total effects on 'techinfo'	Total effects on 'uptech'	Total effects on 'intech'
Educs	−0.24 (−3.24)	0.03 (2.26)	0.25 (3.98)	0.06 (2.68)	0.20 (3.20)	0.12 (3.11)
Profits	–	–	–	–	−0.81 (−12.33)	−0.49 (−8.74)
Employs	−0.20 (−2.54)	–	–	–	0.16 (2.49)	0.10 (2.42)
Income	−0.59 (−12.01)	0.20 (4.32)	0.41 (6.78)	0.41 (8.26)	0.54 (11.79)	0.67 (18.72)
Chtech	–	–	–	–	0.33 (4.23)	0.20 (3.98)
Info	–	0.11 (2.82)	–	0.24 (3.75)	0.04 (3.07)	0.02 (3.18)
Techinfo	–	0.48 (6.07)	–	–	0.16 (5.43)	0.10 (5.28)
Uptech	–	–	–	–	–	0.61 (10.70)
R-square	0.54	0.23	0.24	0.22	0.83	0.63

* The latent variable scores and observational residuals depend on the unit of measurement in the observed variables. As some of these units are the result of subjective scaling of the observed variables the observational residuals were standardised (rescaled such that they have zero means and unit standard deviations in the sample) (Jöreskog and Sörbom 2007). Total effects represent how much a one unit change in an independent variable will change the expected value of a dependent variable

farms are most likely to be profit-oriented. There are different ways in which to explain the effect of income on perceived usefulness of information sources and frequency of access to technological information (41% and, respectively, 41% *ceteris paribus*), one of which being related to the fixed costs of information acquisition, e.g., the cost of the time spent in accessing and processing the information (Feder and O'Mara 1981). Higher income farms are more likely to be able to cover the information costs related to technology adoption.

Availability of farm labour influences both the behaviour (16% *ceteris paribus*) and intentions (10% *ceteris paribus*) indirectly through profit orientation. The statistically significant relationship between the number of employees and the profit orientation of the farm is consistent with findings from the literature where both higher availability of labour and the focus on profit depict larger farms, which are more likely to be associated with technology adoption. Findings from the literature do not consistently point in the same direction with regard to the impact of labour on adoption and this is mostly due to the different requirements of specific technologies, as some are labour intensive while others may free part of the farm labour for off-farm activities. McNamara et al. (1991) and Dorfman (1996) found that off-farm employment may present a constraint to technology adoption e.g., IPM, as it competes for on-farm time, while others such as Fernandez-Cornejo et al. (2005) found that adoption of some technologies e.g., herbicide-tolerant soybeans, allows flexibility in terms of management time and the possibility to obtain additional income from off-farm activities.

Technological investment has a direct impact (33% *ceteris paribus*) on behaviour and an indirect effect (20% *ceteris paribus*) on intentions – through behaviour. This implies that farmers whose investment in technology had stronger effect on their business, who

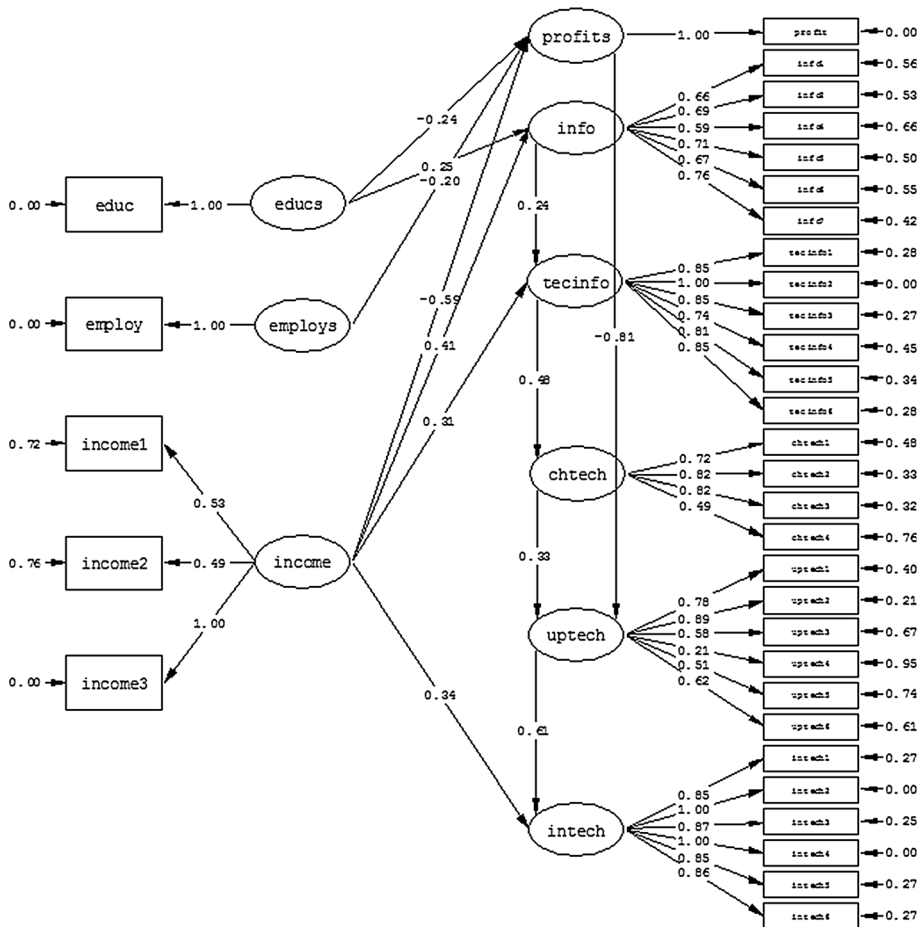


Fig. 4 SEM path diagram (direct effects–standardised solution)

find it easier to invest in technology and who overall exhibit active investment behaviour are more likely to be technology adopters.

Education influences both behaviour (20% *ceteris paribus*) and intentions (12% *ceteris paribus*) indirectly through profit orientation and perceived usefulness of information sources. The impact of education on farm profitability has been demonstrated in the literature (Ali and Flinn 1989). The relationship between education and information seeking behaviour has been analysed in the literature (Bamwine 1997). Viswanath et al. (1994) (as cited in Bamwine 1997) found that membership in socio-economic groups defined by education among other factors influences access to and use of information. More educated farmers are more likely to spend more time to access the information and select and use the most fitting information for their business.

The basic assumption in many studies is that characteristics such as education and income influence farmers' use of information transfer sources, and the use of information subsequently influences technology adoption. Perceived usefulness of information sources has a direct impact (24% *ceteris paribus*) on frequency of access to technological

information, which then directly influences technological investment (48% *ceteris paribus*). Both information variables have a significant indirect effect on adoption (through investment) (4% and, respectively, 16% *ceteris paribus*) and intentions (through investment and behaviour) (2% and, respectively, 10% *ceteris paribus*). Farmers who value information from various sources for the strategic development of the farm business are more likely to be the ones who access information about specific crop technologies more frequently. This confirms findings from other studies (e.g., Reichardt et al. 2009) which found significant correlation between farmers' technological information seeking behaviour and their general information seeking behaviour. The impact of information on technology adoption behaviour and/or intentions has been analysed in most adoption studies whether they focused on the dynamics of innovation diffusion with access and use of information being part of a learning process (Warner 1974; Tsur et al. 1990; Ghadim and Pannell 1999) or on information as a factor of adoption in a cross-section analysis (Reichardt et al. 2009). Our analysis confirms established evidence that access to information (frequency, usefulness perceptions) has a significant effect – either direct or indirect – on technology adoption behaviour and intentions.

And finally, in line with the path dependence concept in the technology adoption literature (Cowen and Gunby 1996; Khanna 2001), our study found that adoption behaviour has a strong significant impact on adoption intentions (61% *ceteris paribus*). Thus farmers who have adopted new crop technologies during the past ten years are more likely to adopt other technologies in the next ten years.

4 Conclusions

Our study analysed the factors influencing multiple technology adoption by Scottish crop farmers and tested the impact of factors common to all technologies with the aim of demonstrating what proportion of the variance in technological uptake/intentions is explained by these factors. The results confirm findings from the literature that, in addition to economic factors, access to technological information and trust in/perceived usefulness of the different information sources influence technological uptake.

To encourage the use of a particular technology, identification of the most likely adopters is useful to avoid the costs involved in reaching those who are not likely to adopt the technology. Our study suggests that the key characteristics for identifying likely adopters of crop technologies such as precision farming, new tillage practices, novel crops, GM crops, biological control methods, and nitrogen fixing plants and/or legumes are: higher education level, active information seeking behaviour, profit orientation, higher agricultural income and proportion of SFP in total income, higher number of farm employees and positive investment behaviour.

The findings are highly policy relevant as they give some indication on the factors influencing the process of targeting specific technological information transfer through the appropriate channels to the most likely technology adopters amongst agricultural producers, which builds a potential driver of behavioural change. As education and information access were found to be among the factors influencing multiple technology adoption, attention should be paid to the provision of education and training on implementation of joint technologies and their collective impact on farm. Läpple et al. (2015) suggest the creation of centers of excellence that focus on particular aspects of farming and provision of professional development courses which could strengthen the links between

research, education, extension and farmers, leading to the co-creation of knowledge better adapted to the needs of farmers. Reichardt et al. (2009) suggest creation of demonstration farm networks, incorporating technology such as precision agriculture firmly within the agricultural education curricula, and creation of knowledge exchange platforms. Farmers' adoption of interrelated agricultural innovations suggests the need for careful coordination between policies encouraging the adoption of some innovations with those promoting others.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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